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14. ABSTRACT

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(1) Arena data have historically served all these communities well.
(2) There are several shortcomings with the use of arena data.
(3) All communities are interested in non-traditional methods for predicting fragmentation.
(4) Several models now exist that solve part of the problem of predicting fragmentation data but no comprehensive package now exists that will completely characterize the fragmentation of a weapon.
(5) There has been enough progress in recent years to channel the various efforts to create one analytical tool that meets the needs of all communities.

One purpose of this paper is to present a survey of the work that is ongoing in these nontraditional methodologies, whether they are very academic methodologies or more basic first-principles engineering approaches. A second purpose of this paper is to present ongoing plans in the area of fragmentation prediction models.

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THE USE OF PHYSICS-BASED MODELS TO PREDICT FRAGMENTATION OF ORDNANCE

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Abstract–Historically the source of input weapon fragmentation data for safe escape models has been arena tests. These same data collected from arena tests are also used as input for models used by other technical communities such as effectiveness, collateral damage, force protection, and weapon design.

(1) Arena data have historically served all these communities well.

(2) There are several shortcomings with the use of arena data.

(3) All communities are interested in non-traditional methods for predicting fragmentation.

(4) Several models now exist that solve part of the problem of predicting fragmentation data but no comprehensive package now exists that will completely characterize the fragmentation of a weapon.

(5) There has been enough progress in recent years to channel the various efforts to create one analytical tool that meets the needs of all communities.

One purpose of this paper is to present a survey of the work that is ongoing in these non-traditional methodologies, whether they are very academic methodologies or more basic first-principles engineering approaches

A second purpose of this paper is to present ongoing plans in the area of fragmentation prediction models.

TABLE OF CONTENTS

1. Introduction

Since the first effectiveness and weapon design models were developed in the very early days of mainframe computers, the source of input weapon fragmentation data for these models has been arena tests. These same data collected from arena tests are also used as input for safe escape models currently used by all the services as well as recently developed collateral damage and force protection models. Several comments are apparent concerning these arena tests:

a. Arena data have served all the communities well over the years of its use.

b. There are several shortcomings with the use of arena data:

- Arena tests are extremely expensive and are becoming more so.
- Only a small portion of fragments can be recovered regardless of the design of the tests.
- Data reduction is often an art rather than a science. Two persons reducing the same data will often end with different results.
- Arena data results are deterministic; many people using arena data now feel that the fragmentation data should be in the form of probability distributions rather than deterministic.
- Developmental weapons cannot always be tested at the time data are required.
- Certain weapons such as terrorist weapons cannot be arena-tested.

c. All communities are interested in non-traditional methods for predicting fragmentation.

d. Several models now exist that solve part of the problem of predicting fragmentation data to augment arena tests or to generate data when arena data are not available.

e. No comprehensive package now exists that will completely characterize the fragmentation of a weapon.

f. There has been enough progress in recent years to try to channel the various efforts to create one analytical tool that meets the needs of all applicable communities.

2. Historical Background

The Ballistics and Safe Escape Group of the Naval Air Systems Team in 1997 submitted a proposal to the Central Test and Evaluation Investment Program (CTEIP) funded by the Office of the Secretary of Defense to investigate these various efforts that were ongoing around the USA and abroad. Because of lack of funding at that time, this effort was not funded.

Since the submission of that proposal, the Naval Air Systems Team and the Naval Surface Warfare Center co-sponsored a workshop that was attended by over eighty scientists working in this area. The consensus of this workshop and the opinions expressed by scientists within all branches of the Department of Defense as well as members of the intelligence community have made it desirable to pursue alternate sources of funding for this effort. These scientists' opinions and current efforts to attract funding are discussed below.

3. Historic / Current Efforts

For many years, both the Air Force and Navy have used approximations to arena data based on simple engineering estimates incorporating data from arena tests for similar weapons or even the same basic weapon with a different explosive fill. In addition, classical physics expressions such as Mott's Distribution for mass prediction and the Gurney Formulas for predicting initial velocity have been used by all the services. In more recent years, more precise methods such as hydrocodes have been used at several academic and defense contractor sites. At the Albuquerque office of the Applied Research Associates (ARL), they have developed and enhanced the SHARC Hydrocode. This code, which is based on the basic physical concepts of conserving mass, momentum and energy, has been used to predict the fragmentation for the AUP round originally developed by Eglin Air Force Base and currently being added to the Navy inventory of weapons as the BLU-116.

Historic efforts for the Air Force include the use of the same Mott's distribution discussed above to predict mass as well as another classical physics distribution, the Held's Distribution. These efforts, both at Eglin Air Force Base as well as support contractors such as OTI, Inc., also have used the Grady Model as well as the Glenn and Chudnovsky Formula for Strain Energy Effects. These same activities have also used several hydrocodes, including Euler and Lagrange Codes and the more precise Smooth Particle Hydronamics Hydrocode, which is discussed in more detail below.

At the Army Research Laboratory in Aberdeen, MD, and the Aberdeen office of ARA, their efforts have centered on applying statistical distributions to the basic arena data. In particular they have applied Gaussian distributions to arena data, assuming these distributions to all four of the basic parameters associated with arena data:

1. **Number of Fragments**
2. **Fragment Mass**
3. **Fragment Initial Velocity**
4. **Fragment Shape Factor**

A novel approach to predicting warhead fragmentation has been taken by Dr. Steve Thaler, President of Imagination Engines, Inc. Under contract to the Munitions Directorate at Eglin Air Force, Dr. Thaler has developed a neural network model that uses databases of historic arena data to predict fragmentation in a matter of seconds on a personal computer. The accuracy of this neural network approach is greatly dependent on the accuracy of these databases and the neural relationship of various warhead / explosive fill combinations. This model has tremendous potential in warhead design and parametric studies for variations in explosive fills. Dr. Thaler, in discussing his model, states: "The methodology has been mapped out and exercised", and "The system will become smarter with more data".

The hydrocode that has demonstrated enormous promise is the Smooth Particle Hydronamics (SPH) mentioned earlier. This very precise code is very high fidelity and very robust. Dr. Larry Liberski and his fellow researchers originally developed this at New Mexico Institute of Technology during the early

to mid 1990's. Dr. Charles Wingate and his associates now maintain this code at Los Alamos National Laboratory (LANL). This hydrocode requires large computer resources but its robustness allows easy reformulation for new physics principles. This hydrocode was invaluable in characterizing the fragmentation of the AUP and was tested extensively during that time period. Two future projects are planned for SPH. One is a cooperative effort with weapon designers at the Weapons Division of the Naval Air Warfare Center, the other an arena test of a foreign mine at the New Mexico Institute of Technology for the Rapid Airborne Mine Clearance System (RAMICS) being developed for the Marines.

4. Funding Sources

Four sources of funding are currently being pursued:

- **Central Test and Evaluation Investment Program (CTEIP)**
- **Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME)**
- **Technical Support Working Group (TSWG)**
- **Defense Modeling and Simulation Office (NMSO)**

The first two are more traditional programs which the Air Force and Navy have participated in for several years. The others are newer programs that have been started in response to the terrorist threat not only to the Department of Defense but also to other departments and agencies in the U. S. Government and several foreign governments.

a. The Central Test and Evaluation Investment Program (CTEIP), is funded by RDT&E funds under the Office of the Secretary of Defense (OSD). The Seek Eagle Office at Eglin Air Force Base administers the Weapons Modification and Simulation Capability (WMASC) funds under CTEIP. The following are the objectives of CTEIP:

(1) Reduce dependency on testing
(2) Reduce manpower
(3) Maintain same certification timeline
(4) Reduce certification time

As discussed above, Code 4.11.2 at the Aircraft Division of the Naval Air Warfare Center submitted a proposal to CTEIP in January of 1997. This 5-year, $5.5 million proposal was enthusiastically endorsed by the Army and Air Force representatives on the tri-service oversight committee but was not approved because of opposition of the Navy representative on the committee.

This proposal was to use a four-phase approach as follows:

Phase 1 – Feasibility Study
Phase 2 – Methodology Assessment
Phase 3 – Environmental Evaluation
Phase 4 - Tri-Service Approval

To accomplish the CTEIP objectives, an Integrated Product Team (IPT) would be formed that would be chaired by the Ballistics and Safe Escape Group at the Aircraft Division of the Naval Air Warfare Center and would include representatives from all three services. This IPT would also include members from joint commands such as the Joint

Warfare Analysis Center and the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME). Representatives of other government departments and agencies such as the CIA and the FBI would also be invited to become members of the IPT.

Current plans are to resubmit the proposal that was not funded in 1997 and to broaden the scope of the proposal to include not only the safe escape community use of the funds that would be available under CTEIP but the other interested communities listed above. Since the original submission four years ago, two important advancements have occurred: (1) computer technology has advanced to the point that many of the models now available for fragment prediction can be run on personal computers, and (2) many of the models that were just being developed in 1997 have been used with considerable success. In addition, the political climate for the proposal has changed since 1997 to the point that there seems to be a good chance that the proposal will be funded in this next submission cycle.

b. The Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME) has as its primary mission the development and publication of weapons effectiveness estimates for all nonnuclear weapons. One of its primary functions is to standardize methodologies used by the services and industry for the evaluation of nonnuclear munitions effectiveness.

This group has supported the concept of Physics-Based modeling since their chief Navy representative attended the workshop co-sponsored by the Dahlgren Division of the Naval Surface Warfare Center (NSWCDD) and the Aircraft Division of the Naval Air Warfare Center (NAWCAD) in May 1998. Following this workshop, the project was made a priority for the Steering Committee for JTCG. However, until recently this group had no funds to support this effort. Within the past year plans for increasing the funding for this group have been announced and a meeting is planned with the JTCG/ME to seek funding to support the Physics-Based Modeling effort. This meeting will include representatives from both NSWCDD and NAWCAD, the two primary activities that will co-sponsor the proposal. The principal JTCG/ME attendee will be the head Navy representative to that group. The proposal to JTCG/ME will emphasize the same four-step approach as proposed to CTEIP, emphasizing the use of the results from the proposed study in the areas of effectiveness, safe escape, and collateral damage.

c. The Technical Support Working Group (TSWG) is an interagency group formed in the late 1980's to combat the terrorism threat not only to the services of the United States but also to the general civilian population. The following nine departments of the federal government are represented on this working group:

(1) Defense
(2) State
(3) Treasury
(4) Justice
(5) Agriculture
(6) Energy
(7) Health and Human Services
(8) Commerce
(9) Transportation.

In addition to these nine departments, several other federal agencies are represented in the working group:

(1) Central Intelligence Agency
(2) Environmental Protection Agency
(3) Federal Emergency Management Agency
(4) General Services Administration
(5) US Postal Service
(6) National Forensic Laboratory.

The TSWG also has bilateral agreements with the following three countries:

(1) Canada
(2) United Kingdom
(3) Israel.

The stated mission for TSWG is "to conduct the national interagency research and development program for combating terrorism through rapid research, development and prototyping." Two of the techniques identified by the working group to accomplish this mission are as follows: (1) "Identify requirements, develop solutions, and fund and execute projects", and (2) "Customize technology to specific users needs".

The proposal to TSWG would be much broader than the CTEIP and JTCG/ME proposals but an integral part of any proposal to combat terrorist weapons has to be methodology to predict fragmentation of these weapons. This community is a prime example of the point made earlier on the unavailability of arena data as input for certain models requiring these data. This proposal would be a joint proposal submitted by both the Aircraft Division of the Naval Surface Warfare Center and the Dahlgren Division of the Naval Air Warfare Center.

d. The mission of the Defense Modeling and Simulation Office (DMSO) Science and Technology (S&T) Initiatives Division (STID) is to leverage S&T advances to provide warfighters with superior and affordable modeling and simulation technology to support their mission and to give them revolutionary war-fighting capabilities. To achieve this, the STID seeks to identify and pursue the most promising modeling and simulation techniques within a broad spectrum of the science and engineering research communities and to develop those technologies into important, new military modeling and simulation capabilities. To accomplish this goal, STID has solicited proposals for advanced research and development in several technical areas. Proposals should evolve and demonstrate new technology and must demonstrate that the proposed effort is aimed at mature / high-payoff technologies that have the potential for making large incremental, or somewhat revolutionary, improvements to current DoD modeling and simulation capabilities.

The primary area of interest that the Physics-Based Modeling will address is the conduct of Operations Other Than War (OOTW). OOTW has become an extremely important part of the US military's responsibility since the end of the Cold War. OOTW includes operations that encompass the use of military capabilities across the range of military operations short of war. These military operations can be applied to complement any combination of the other instruments of national power and occur, before, during, and after war. The

DMSO STID is seeking technologies that will enhance the modeling and simulation of OOTW.

DMSO has also emphasized the desirability of developing modeling and simulation capabilities that may have non-military application. The possible application of the Physics-Based modeling to the terrorist threat falls under this desired capability.

As with the TSWG proposal, this DMSO STID proposal will emphasize the Physics-Based Modeling concept as part of a larger terrorist-threat proposal. This proposal also would be a joint proposal submitted by both the Aircraft Division of the Naval Surface Warfare Center and the Dahlgren Division of the Naval Air Warfare Center.

5. Conclusions

Over the past four years, numerous discussions have been held with personnel from all three services as well as officials from the CIA, the State Department and the academic world. These discussions have always ended with the conclusion that there is a definite need for Physics-Based models that will be used to supplement the data historically generated by arena tests. The other conclusion reached in these discussions is that now is the proper time to implement such a model. Computer and numerical methods technology have advanced to the point that not only is such modeling within the realm of possibility but actually is possible today.

The structure of the modeling should be multi-tiered. While the hydrocodes such as SPH offer the most accurate methodology for solving the problem, the computer assets required are costly and time-consuming. In addition, for many of the problems needing fragmentation the outputs from these hydrocodes are more accurate than needed by the models that require these type inputs. Safety type models such as safe escape and range safety require these higher fidelity outputs but models used for weapon design and parametric studies require less precise predictions. In addition, the inputs required by these hydrocodes models are often lacking so the higher-fidelity models can not produce the required data. In these cases, lower fidelity models yield acceptable results. Thus a multi-tiered approach is the best overall solution, using a combination of low and high fidelity models.

Because the fragment prediction problem cuts across so many communities, the funding should come from multiple sources. All four sources discussed in this paper are targets for funds to support this effort:

- **Central Test and Evaluation Investment Program (CTEIP)**
- **Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME)**
- **Technical Support Working Group (TSWG)**
- **Defense Modeling and simulation Office (NMSO)**